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TRANSPORTATION VEHICLE ENERGY INTENSITIES
(A Joint DOT/NASA Reference Paper)

Alfred C. Mascy

NASA Ames Research Center
Moffett Field, California 94035

Robert L. Paullin

Department of Transportation
Washington, D.C. 20590

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16. Abstract

This reference paper represents a compilation of data on the energy consumption of air and ground vehicles.

The ratio BTU/ASM, British Thermal Units/Available Seat Mile, is used in this paper to express vehicle energy intensiveness, and relates to the energy consumed directly in producing seat-mile or ton-mile productivity.

Data is presented on passenger and freight vehicles which are in current use or which are about to enter service, and advanced vehicles which may be operational in the 1980's and beyond. For the advanced vehicles, an estimate is given of the date of initial operational service, and the performance characteristics.

Although the data is predominantly technical, other key considerations in interpreting energy intensiveness for a given mode are discussed, such as: load factors, operations, overhead energy consumption, and energy investments in new structure and equipment.

The data presented in this paper was provided by the primary federal agency responsible for research on specific transportation modes. It is expected that this paper will be updated in the future as better data becomes available.

Readers are invited to submit suggestions for changes to either or both of the authors.

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TRANSPORTATION VEHICLE ENERGY INTENSITIES
(A Joint DOT/NASA Reference Paper)

Prepared by an
Interagency Working Group
National Aeronautics and Space Administration
Department of Transportation
Washington, D.C.

June 20, 1974

Robert L. Paullin
Office of R&D Policy
Department of Transportation
Washington, D.C. 20590

Alfred C. Mascy
System Studies Directorate
NASA Ames Research Center
Moffett Field, California 94035

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PREFACE

An interagency working group was formed in March 1974 to develop a reference paper on transportation vehicle energy intensiveness. Representatives to the group were:

Mr. R. Paullin, DOT/OST
Mr. R. Husted, DOT/OST
Mr. D. Ryan, Jr., DOT/OST
Mr. M. Miller, DOT/TPI
Mr. R. Winestone, DOT/TPI
Mr. W. Devereaux, DOT/OST
Mr. M. Cheslow, DOT/TPI
Cmdr. I. Jacobson, DOT/CG
Mr. J. Spriggs, DOT/FAA
Mr. T. Milton, DOT/CG
Mr. R. Pinnes, DOT/OST
Mr. J. Christensen, NASA/RO
Mr. R. Nutter, DOT/TPI
Mr. R. Nysmith, NASA/RD
Mr. F. Mascy, NASA/ARC
Mr. A. French, DOT/FHWA
Mr. J. Tucker, FAA
Mr. V. Oakes, FAA
Dr. R. Strombotne, DOT/OST
Mr. D. Novotny, DOT/FRA

I. INTRODUCTION

A. General

This reference paper has been prepared in response to a need for a source of energy intensiveness data to be used in various transportation system studies. It is a compilation of data on the energy consumption of air and ground vehicles.

Comparisons between vehicles are not made nor are conclusions or recommendations presented. The reader is cautioned against drawing conclusions based solely on the data presented herein.

Data is presented on passenger and freight vehicles which are in current use or which are about to enter service, and advanced vehicles which may be operational in the 1980's and beyond. For the advanced vehicles, an estimate is given of the date of initial operational service, and the performance characteristics. Qualifying information is given for each vehicle to help insure an understanding of the assumptions made for each mode. There are many variations within each vehicle type which are not included in the tabulations; instead, reasonable composite values are given. Vehicles are not identified by manufacturers, but are grouped in general categories.

Although the data is predominantly technical, load factors, operational considerations, overhead energy consumption, and energy investments in new structure and equipment are also key considerations in interpreting energy intensiveness for a given mode. Some of these considerations are discussed.

Data on passenger ships is not included in this paper, since there are very few in service in the United States and no U.S. flagships on the high seas. Within the contiguous states, passenger service is limited to ferry boats and recreational craft. In comparison to highway rail and air passenger service, passenger ship service is very limited. For these reasons, passenger ship data is not included in this paper.

The data presented in this paper was provided by the primary federal agency responsible for research on specific transportation modes. It is expected that this paper will be updated in the future as better data becomes available.

Readers are invited to submit suggestions for changes to either or both of the authors.

B. Vehicle Energy Intensiveness

An operating ratio often used in transportation systems analyses is Direct Operating Costs per Available Seat-Mile (DOC/ASM), for a specified vehicle type. This ratio reflects the dollar costs directly involved in operating a vehicle which are incurred in producing a seat-mile of productivity.

Similarly, an operating ratio related to energy intensiveness, receiving attention because of concern for energy conservation, is British Thermal Units per Available Seat-Mile (BTU/ASM), for a vehicle type.

The ratio BTU/ASM is used in this paper to express vehicle energy intensiveness. In most cases, the values given are basic values in that they represent the energy consumed in the final conversion process; e.g., the gasoline carried in the tank of the automobile and burned as the automobile moves. Other related considerations can also be expressed by other dimensions. These are: load factor, operational aspects, overhead energy consumption, and energy investment. Section IV of this paper contains a discussion of related vehicle energy intensiveness factors.

The data presented herein for passenger and freight vehicles relate to the energy consumed directly in producing seat-mile or ton-mile productivity. These data do not include estimates of conversion efficiencies in the processing of raw materials into the final energy product consumed in transportation. This is one of the reasons that the reader has been cautioned from drawing conclusions about the relative energy efficiency of various modal transportation systems based solely on comparisons of energy intensiveness vehicle data presented in this paper.

II. ENERGY INTENSIVENESS FOR VARIOUS TYPES OF PASSENGER VEHICLES

A. Auto and Bus

Table I contains a summary of passenger cars and buses for the time period of 1974-1980. Table II contains a summary of passenger cars and buses for the time period after 1980. Data for these charts have been supplied by Mr. A. French, Chief, Highway Statistics

TABLE I

ENERGY INTENSIVENESS FOR AUTOMOBILES AND BUSES
1974-1980

Vehicle Type	Gross Weight (1000 lbs.)	Trip Length (Statute Miles)	Average Trip Hrs @ MPH	Fuel Type[1]	Vehicle Statute Miles/Gal	Number of Seats		Specific Energy, Stop/Start			
								Seat-Miles/Gallon		BTU's Seat-Mile	
						Available (Full Load)	1972 Actual Aver. Oper.	Available (Full Load)	1972 Actual Aver. Oper.	Available (Full Load	1972 Actual Aver. Oper.
Urban, Subcompact Auto	2.0-2.4	10.0	.24/25	Gas	24.0	4.0	1.6	96	38.4	1,302	3,255
Urban, Compact Auto	2.5-3.4	10.0	.24/25	Gas	18.0	5.0	1.6	90	28.8	1,389	4,340
Urban, Standard Auto	3.5-4.4	10.0	.24/25	Gas	14.4	6.0	1.6	86.4	23.0	1,447	5,435
Urban, Luxury Auto	4.5-6.0	10.0	.24/25	Gas	9.0	6.0	1.6	54	14.4	2,315	8,681
Urban, Bus	(18.5 Empty) 20.3-3-26.0	13.0	1.25/ 10.3	Diesel	3.6-4.0	50	12	180	48	771	2,891
Intercity, Bus	(28.7 Empty) 45.0	100.0	1.81/55	Diesel	6.0	46	19.4	276	116.4	503	1,192
Intercity, Subcompact Auto	2.0-2.4	100.0	1.81/55	Gas	30.0	4.	2.0	120	60	1,042	2,083
Intercity, Compact Auto	2.5-3.4	100.0	1.81/55	Gas	22.5	5.	2.2	112.5	49.5	1,111	2,525
Intercity, Standard Auto	3.5-4.4	100.0	1.81/55	Gas	18.0	6.	2.6	108	46.8	1,157	2,671
Intercity, Luxury Auto	4.5-6.0	100.0	1.81/55	Gas	13.0	6.	3.0	72	36	1,736	3,472

[1] Gasoline = 125×10^3 BTU/gallon, Diesel = 138.8×10^3 BTU/gallon

TABLE II

ENERGY INTENSIVENESS FOR AUTOMOBILES AND BUSES
1980+

Vehicle Type	Gross Weight (1000 lbs.)	Trip Length (Statute Miles)	Average Trip Hrs @ MPH	Fuel Type[1]	No. of Seats	Vehicle Statute Miles/Gal	Available Seat-Miles Per Gallon	BTU's Avail. Seat-Miles (X1000)	Estimated Initial Operational Dates
Urban, Subcompact Auto	2.0-2.4	10	.24/25	Gas	4	35	140	892	1974
Urban, Compact Auto	2.5-3.4	10	.24/25	Gas	5	30	150	925	1960
Urban, Standard Auto	3.5-4.4	10	.24/25	Gas	6	25	150	1,110	1980
Urban, Luxury Auto	4.5-6.0	10	.24/25	Gas	6	20	120	1,157	1979
Urban, Bus	20-25.0	13	1.25/10.3	Diesel	50	5	250	552	1980-1990
Intercity, Bus	45	100	1.67/60	Diesel	50	10	500	278	1980-1985
Intercity, Subcompact Auto	2.0-2.4	100	1.67/60	Gas	4	40	160	867	
Intercity, Compact Auto	2.5-3.4	100	1.67/60	Gas	5	35	175	793	1980
Intercity, Standard Auto	3.5-4.4	100	1.53/60	Gas	6	30	180	771	1980
Intercity, Luxury Auto	4.5-6.0	100	1.42/60	Gas	6	25	150	925	

[1]Gas = 1.25×10^3 BTU's/Gallon. Diesel = 138.8×10^3 BTU's/Gallon. By 1980 or 1990 it is anticipated that most new cars and light trucks can have engines using fuel injection and other new technologies that will use middle distilate fuel, thereby reducing energy required for refining and freeing expensive light fractions for petro-chemical feed stock.

Division, the Federal Highway Administration. It should be noted that the left-hand columns for available seat-miles/gallon and BTU/available seat-miles contains data for the ideal full load condition, and the right-hand column for both of these parameters contains data for the "typical" 1972 actual (average) operation.

B. Passenger Aircraft

Table III contains a summary of energy intensiveness for various types of passenger aircraft for the period 1974-1980. Table IV contains a summary of energy intensiveness for various types of passenger aircraft estimated to be operational in the post-1980 period. The data contained in Tables III and IV was compiled by Mr. F. Mascy, Aerospace Engineer, Systems Study Division, Ames Research Center, NASA, and by Mr. Vance Oakes and Mr. J. Tucker, Senior Policy Analysts, Office of Aviation Policy and Plans, FAA.

C. Passenger Trains

Table V contains a summary of energy intensiveness for various types of passenger trains for the period 1974-1980. Table VI contains a summary of energy intensiveness for various types of passenger trains for the post-1980 period. The data for urban trains was compiled by Mr. P. Morgan, Deputy Associate Administrator, Office of Research and Development, Urban Mass Transportation Administration. The data for intercity trains was compiled by Mr. R. A. Novotny, Advanced Systems Division, Office of Research, Development and Demonstration, Federal Railroad Administration.

TABLE III

ENERGY INTENSIVENESS FOR PASSENGER AIRCRAFT, 1974-1980

Mode	Number of Seats	Gross Weight (1000 lbs)	Specific Trip Length (S.M.)	Average Trip Time (Hrs)[1]	Vehicle Statute Mi/Gal.	Energy, Available Seat-Mi. Per Gal.	Stop/Start BTU/Avail. Seat-Mi. (×1000)[2]	Fuel Type	Data Provided By
Aircraft[3]									
Helicopter[4]	24-26	19	13	0.15	.58-.71	14-18	6.65-8.87	Kero	NASA ARC
Gen Avia Single Eng Recip.[5]	4-6	2.3-3.8	100	0.6-0.8	10.5-15.1	42-72	1.49-2.56	Avgas	"
Gen Avia Twin Eng Recip.[5]	6-11	3.6-8.8	250	1.2-1.5	4.8-10.2	40-61	1.75-2.70	Avgas	"
Turbo Prop	98	113	250	0.8	.38	37	3.32	Kero	"
Turbo Prop	98	113	500	1.3	.47	46	2.68	Kero	"
Twin Eng Turbo Fan (NB)	68-106	77.7-116	250	0.8	.34-.44	30-38	3.22-4.15	Kero	"
Twin Eng Turbo Fan (NB)	68-106	77.7-116	500	1.3	.44-.54	37-47	2.61-3.35	Kero	"
Twin Eng Turbo Fan (NB)	68-106	77.7-116	1000	2.3	.51-.61	41-54	2.30-2.97	Kero	"
3 & 4 Eng Turbo Fan (NB)	131-200	173-350	250	0.8	.15-.22	27-30	4.06-4.62	Kero	"
3 & 4 Eng Turbo Fan (NB)	131-200	173-350	500	1.3	.21-.29	35-41	3.00-3.48	Kero	"
3 & 4 Eng Turbo Fan (NB)	131-200	173-350	1000	2.3	.26-.34	44-51	2.40-2.78	Kero	"
3 & 4 Eng Turbo Fan (WB)	256-385	426-775	250	0.8	.09-.15	33-42	2.96-3.75	Kero	"
3 & 4 Eng Turbo Fan (WB)	256-385	426-775	500	1.3	.11-.19	44-51	2.40-2.80	Kero	"
3 & 4 Eng Turbo Fan (WB)	256-385	426-775	1000	2.3	.14-.22	54-60	2.07-2.30	Kero	"
3 Eng Turbo Fan Charter (WB)	400	426	250	0.8	.14	57	2.18	Kero	"
3 Eng Turbo Fan Charter (WB)	400	426	500	1.3	.17	70	1.77	Kero	"
3 Eng Turbo Fan Charter (WB)	400	426	1000	2.3	.20	79	1.57	Kero	"

[1]Commercial Transport Trip Times obtained from "Official Airline Guide," January 15, 1974, schedule times plotted versus trip distance.

[2]Kerosene at 18,400 BTU/lb and 6.7 lb/gallon; Avgas at 18,700 BTU/lb and 5.75 lb/gallon.

[3]With the exception of helicopter and general aviation data, all other fuel consumption data obtained directly from manufacturers.

[4]From CAB "Aircraft Operating Cost and Performance Report," August 1972.

[5]Based on Manufacturer's published performance data for cruise at 75% power, block time and speed estimated at 90% of cruise speed to allow for takeoff and landing.

TABLE IV

ENERGY INTENSIVENESS FOR PASSENGER AIRCRAFT, 1980+

Mode	Potential Change[1] Increase In Vehicle Statute Mi/Gal.	Potential Change[1] Increase in Avail. Seat-Mi. Per Gal.	Potential Change[1] Decrease in BTU/Avail. Seat-Mi.	Estimated Initial Operational Dates	Data Provided by
Aircraft					
Modification of Existing Equipment	10-25%	10-25%	10-20%	1980	NASA ARC
Derivatives of Existing Designs	25-67%	25-67%	20-40%	1980-1985	"
Net Designs Using 1974 Technology	67-100%	67-100%	40-50%	1980-1985	"
New Designs With 1980 Technology	67-190%	67-190%	40-66%	1985-1990	"

[1]All estimates based on initial results of current studies at Ames Research Center/Systems Studies Division, the Langley Research Center/Aeronautical Systems Office, and the Lewis Research Center/Wind Tunnel and Flight Division.

TABLE V - Energy Intensiveness for Passenger Trains, 1974-1980

Vehicle Type	Gross Weight (1000 lbs)	Trip Length (Statute Miles)	Aver. Trip Time (Hrs)	Fuel Type	Vehicle Statute Miles/Gal	Number of Seats	Specific Energy Stop/Start	
							Seat-Miles Gallon	BTU's/ Seat-Mile
Urban Train	79	.75	.02	Elect.	57,600 BTU/mi[1]	50-60	106	1320
Metroliner	1050	75	1.0	Elect.	0.83	382	318	440
New Tokaido Line	2000	140	1.4	Elect.	0.4	1400	305	427
Std. Diesel	1200	50	0.75	Diesel	0.66	360	240	583

TABLE VI - Energy Intensiveness for Passenger Trains, 1980+

									Est. Oper. Date
Turbotrain (AMTRAK)	600	50	.5	JP-4	0.55	314	204	690	1976
Improved Passenger Train	1200	75	.6	Elect.	0.76	600	390	360	1982
Tracked Levitated Vehicle	300	100	.4	Elect.	0.41	300	78-113	1920 1330	1985

[1]Includes gen. eff. of .4 and is based on 7 kilowatt-hrs/mile and 3413 BTU/kilowatt-hr.

III. ENERGY INTENSIVENESS FOR VARIOUS TYPES OF FREIGHT VEHICLES

Freight Vehicles. The energy intensiveness for freight vehicles is summarized in Tables VII-XII. Table VII contains data for trucks for the time period of 1974-1980 and Table VIII contains truck data for the post-1980 time period. Data for Table VII and VIII was compiled by Mr. A. French, Chief of the Highway Statistics Division, Federal Highway Administration. Tables IX and X contain data for freight aircraft. This data was compiled by Mr. F. Mascy, Aerospace Engineer, Systems Study Division, Ames Research Center, NASA, and Mr. Vance Oakes and Mr. J. Tucker, Senior Policy Analysts, Office of Aviation Policy and Plans, Federal Aviation Administration. Tables XI and XII contain data on freight trains supplied by Mr. R. Novotny, FRA.

TABLE VII - ENERGY INTENSIVENESS FOR TRUCKS, 1974-1980

Vehicle Type	Cargo Density Lbs/Ft^3	Maximum Payload in Tons	Trip Length (Statute Miles)	Average Trip Time Hrs @ MPH	Type of Fuel	Vehicle Statute Miles/ Gallon	Specific Energy Stop/Start Cycle	
							Ton-Miles Per Gallon	BTU's/Ton Mile
Urban, Truck	20-100	8	10	.4/25	Gas	8	64	1,953
Urban, Truck	20-100	8	10	.4/25	Diesel	12	96	1,446
Urban, Truck	10-30	3.1	10	.4/25	Gas	8	25	5,040
Intercity, Truck	20-100	25	100	1.8/55	Diesel	5	125	1,110
Intercity, Truck	15	14.3	100	1.8/55	Diesel	4.8	69	2,023

TABLE VIII - ENERGY INTENSIVENESS FOR TRUCKS, 1980+

Urban, Truck	20-100	12	10	.4/25	Diesel	15	120	1,157
Intercity, Truck	200-100	75	100	1.53/65	Diesel	5	375	370

TABLE IX - ENERGY INTENSIVENESS FOR FREIGHT AIRCRAFT, 1974-1980

Mode	Maximum Payload (Tons)	Payload Gross Density (lb/ft^3)	Specific Trip Length (S. Mi.)	Average Trip Time (Hrs)[1]	Vehicle Statute Mi/Gal	Specific Energy, Stop/Start Cycle: Ton-Mi Per Gal	Specific Energy, Stop/Start Cycle: BTU/Ton Mi (×1000)[2]	Fuel Type	Data Provided By
AIRCRAFT[3]									
Turbofan, Narrow Body	20.6-58.7	8.3-11.6	500	1.3	.19-.44	8.4-11.1	11.1-14.7	Kero	NASA ARC
Turbofan, Narrow Body	20.6-58.7	8.3-11.6	1000	2.3	.22-.53	9.6-12.8	9.6-12.9	Kero	NASA ARC
Turbofan, Narrow Body	46.8-58.7	10.9-11.6	2000	4.4	.23-.27	12.6-13.6	9.1-9.8	Kero	NASA ARC
Turbofan, Wide Body	77.9-126.0	10.0	1000	2.3	.12-.23	13.7-15.0	8.2-9.0	Kero	NASA ARC
Turbofan, Wide Body	77.9-126.0	10.0	2000	4.4	.13-.24	14.2-16.0	7.7-8.7	Kero	NASA ARC

[1]Trip times assumed same as passenger schedules obtained from "Official Airline Guide," January 15, 1974, schedule times plotted against trip distance.

[2]Kerosene at 18,400 BTU/lb and 6.7 lb/gallon.

[3]All fuel consumption data obtained directly from aircraft manufacturers for all-freighter or convertible-freighter aircraft models.

TABLE X - ENERGY INTENSIVENESS FOR FREIGHT AIRCRAFT, 1980+

Mode	Potential Change[1] Increase In Vehicle Statute Mi/Gal.	Increase In Avail. Ton-Mi. Per Gal.	Decrease in BTU/Avail. Ton-Mi.	Estimated Initial Operational Dates	Data Provided By
AIRCRAFT					
Modification of Existing Equipment	10-25%	10-25%	10-20%	1980	NASA ARC
Derivatives of Existing Designs	25-67%	25-67%	20-40%	1980-1985	NASA ARC
New Designs Using 1974 Technology	67-100%	67-100%	40-50%	1980-1985	NASA ARC
New Designs With 1980 Technology	67-190%	67-190%	40-66%	1985-1990	NASA ARC

[1] All estimates based on initial results of current studies at Ames Research Center/Systems Studies Division, the Langley Research Center/Aeronautical Systems Office, and the Lewis Research Center/Wind Tunnel and Flight Division.

TABLE XI - ENERGY INTENSIVENESS FOR FREIGHT TRAINS, 1974-1980

Vehicle Type	Cargo Density $\#/Ft^3$	Maximum Payload, Tons	Trip Length, Statute Miles	Average Trip Time, Hrs @ MPH	Type of Fuel	Vehicle Statute Miles/ Gallon	Specific Energy Start/Stop Cycle	
							Ton-Miles Per Gallon	BTU's Ton-Miles
Intercity Train								
Config I:	25	1000	100	2.26 @ 44	Diesel	0.14	273	550
Config II:	25	7000	100	2.85 @ 35	Diesel	0.17	420	330

TABLE XII - ENERGY INTENSIVENESS FOR FREIGHT TRAINS, 1980+

Intercity Train	25	6000	100	2.5 @ 40	Diesel	0.17	465	300

IV. RELATED CONSIDERATIONS

The energy intensiveness of vehicles, as presented here in seat or capacity ton miles per gallon, is representative of a particular vehicle size operating under specified conditions on a particular trip length. To aggregate the energy consumed by a set of vehicles to the consumption of an operating transportation system requires consideration of the fleet mix and trip length mix as well as a host of operational factors which can add to consumption. In this section we consider briefly the nature and approximate magnitude of the operational factors which convert vehicle energy intensiveness to system or modal intensiveness.

A. Load Factor. The basic output of a transportation system is the passenger or goods actually carried. Commercial carriers use as load factor the ratio of revenue ton or passenger miles to the available seat or the tons capacity moved. Historically, load factor experienced by common carriers has been partly due to carrier policy, partly to marketing success, partly to regulation, scheduling, competition, and the vagaries of demand. Most importantly, in the past 20 years, forces of regulation and competition have tended to keep load factors down near the breakeven level even for viable air and bus modes. Passenger rail, prior to the formation of AMTRAK, operated many unprofitable declining routes over the period and showed correspondingly poor load factors. Local service air lines have had the same problem.

Freight systems have shown relatively poor load factors, partly caused by empty backhauls of specialized or privately owned vehicles. In other cases, the value of delivery time made it profitable to avoid waiting for a full load. Finally, some bulky commodities completely fill the vehicle volume capacity at far less than the rated weight capacity, giving rise to misleading ton-mile statistics.

Until recent energy conservation measured changed regulations and operating procedures, most common carrier modes experienced load factors of 50% or lower. It should be noted that scheduled service is limited in maximum achievable load factor by the variation in demand from hour to hour, day to day, and route to route. It is impossible to serve a fixed route on a fixed schedule with a fixed vehicle fleet and achieve high load factor without being overloaded or turning away passengers at some times and places.

Occupancy rate rather than load factor is given for private automobiles. It should be noted that in the past most private automobiles were sized--as are many common carrier vehicles--by near peak load conditions although peak loads occur relatively infrequently. Thus, a family car may be bought to seat six on vacation trips and be used by only one or two occupants at other times.

B. Operational Aspects. Direct operational considerations of importance are not quantified in this paper, but affect the consumption of the normal vehicle fuel. They fall into three general categories:

1. Primary (revenue) operations. Including such items as speed, schedules, vehicle or train size, route selection, (all of which affect load factor as well as vehicle fuel consumption), terminal procedures, traffic regulation and assignments, etc.

2. Secondary (non-revenue) operations. Including such items as switching and repositioning of equipment, regular maintenance, storage, training, executive or other personnel transport using the normal fuel.

3. Unplanned (emergency) operations. Including such items as operational procedures to deal with adverse weather, equipment breakdowns, unscheduled maintenance, extraordinary traffic delays, etc.

Estimates of industry energy intensiveness from total fuel purchases often lump the additional fuel consumed in the above operations to the basic fuel consumption of the vehicle on normal routes in revenue service. Considered as a reduction factor on the vehicle seat or ton miles per gallon, most modes have achieved an operational efficiency of 60 to 70% in the past. Fuel has always been a cost item, so no commercial carrier intentionally wasted fuel. However, the balancing of fuel against crew cost, maintenance, vehicle utilization, etc. may have resulted in operational patterns no longer appropriate. The indications are that most modes have been able to improve operational efficiency in the interests of energy conservation.

C. Overhead Energy Consumption (indirect). Two system energy consumption items are usually missing from energy intensiveness measure based on primary fuel purchases. For convenience, we use the terms business overhead and fuel overhead.

Business overhead energy consumption includes expenditures of fuel or energy sources, other than that used for vehicle operation, needed in the operation of the business. Thus heating, air conditioning and lighting of offices and terminal, equipment power of all kinds from computers to fork lifts, advertising displays, etc., all add to total energy consumption, but rarely show up in purchases of the principal fuel. As with many overhead items, they may not be directly proportional to passenger miles or ton miles produced, although overhead consumption is a function of the general volume of business.

It should be noted that energy overhead is common to almost all businesses and usually is reported in the commercial or industrial sector rather than transportation. There is little indication that transportation is particularly inefficient in comparison with other businesses or industries on the basis of people employed or dollar volume of business. Among transportation modes, those which have a high ratio of employees to passenger-miles or ton-miles produced, also tend to have higher overhead energy consumption.

On a strict input-output table basis, every business which supplies the transportation operator contributes indirectly to fuel consumption. Thus, if the operator is insured, a fraction of the energy expended by the insurance industry could be attributed to the transportation. From an energy conservation standpoint, the transportation operator has no control over efficiencies in these other industries and can affect consumption only by using less of the product involved or possibly switching to a less energy intensive product. Furthermore, the consumption of energy by the supporting services is reported under the appropriate commercial or industrial sector. To avoid double counting, it appears desirable to consider as overhead only those consumption activities directly connected with the transportation system.

Because business overhead usually involves a different fuel type, it is best treated as an addition to the total system operational fuel energy (in BTU or appropriate energy units) rather than a modification of the passenger or seat miles per gallon. Data on energy overhead are incomplete. For aviation, in which estimates have been made, the added energy is about 8%; for the private auto, about 12%.

Fuel overhead refers to the energy expenditure in production, refining and distribution of the fuel to the point of sale to the transportation user. Since most common carriers are bulk purchasers, distribution energy costs are lower than for private automobiles. (The internal distribution is already accounted for in the business overhead.) The refining of high octane gasoline requires more expenditure of energy than regular gasoline or diesel fuel. The principal offender, high octane aviation gasoline, is no longer used in significant quantity.

The energy expended by the petroleum industry is accounted for in the industrial sector totals. The real importance of the concept of fuel overhead is in the difference between modal fuel types. Thus motor gasoline has an overhead of about 25%, while jet fuel is about 20% and rail or highway diesel fuel is slightly lower.

The heating value of petroleum fuels varies considerably with type and within each general type classification.

Motor gasoline	125000 BTU/GAL
Aviation gasoline	108000 BTU/GAL
Kerosene jet fuel	123000 BTU/GAL
Highway Diesel	138000 BTU/GAL
Railroad Diesel	141000 BTU/GAL
Residual	150000 BTU/GAL

D. Energy Investment. The final item for inclusion in transportation energy intensiveness is the investment in energy represented by the various facilities, structures and equipment connected with a particular transportation system. For an existing transportation system, the fixed facilities such as highways, railroad track or airport runways, the structures in terminals, shops, hangars, office buildings, all the vehicles and other equipment all represent a past expenditure of energy required for construction and fabrication. For accounting purposes, some investigators have treated energy in a manner analogous to money expenditure and charged the system for depreciation of its original energy investment. On such a basis, the energy invested in an aircraft plus engines and spares would add about 3% to the BTU for each passenger mile; for an automobile, about 13% since it produces far fewer passengers miles in its lifetime. Highway construction and maintenance could add about 9% to the auto energy consumption accounting; airport construction and maintenance, about 2% to each passenger mile.

For energy conservation, however, the important point is not the sunk energy cost in existing equipment and structures but the possible new expenditure on new system elements. The useful passenger or ton miles which can be gotten from an old energy investment are a benefit rather than a cost as compared with the added expenditure in a premature investment in a new system. As an example, an automobile which gets 10 mpg is to be replaced before the end of its normal life by one which gets 15 mpg. At the first indication, the saving would be 5 mpg or 50% over the original car. However, by prematurely replacing the old car, expected payoff from its energy investment, amounting to 13% of the direct fuel consumption, is being foregone for the remainder of its expected life. The saving is therefore only 37% over the remainder of the life of the old car. If the new car were a higher technology vehicle requiring greater energy investment than the old, the advantage would be even less.

For the example cited above, the saving is still positive; however, replacement for a 1 mpg gain would involve a net loss rather than a gain because of the energy investment. The value of the energy investment concept is to permit proper discounting of proposed new vehicles or systems.

E. Sample Calculation. As noted, the data on these related considerations is incomplete; furthermore, because of present emphasis on energy conservation, the efficiencies are improving. The sample calculation presented here is for a passenger aviation system for which data are available; the values used are representative but not necessarily exact.

In earlier years commercial aviation operated with a fleet mix and route system for which the average vehicle energy intensiveness was, say, 43 seat miles per gallon. Allowing for an operational efficiency of 70% and a load factor of 49%, the revenue passenger energy intensiveness was 14.8--roughly 15--passenger miles per gallon.

At 123000 BTU per gallon, 14.8 passenger miles per gallon translates to 8300 BTU per passenger mile. For 130 billion revenue passenger miles annual product, the fuel consumption was about 1080×10^{12} BTU or 8.8 billion gallons of jet fuel used in operations.

Overhead charges of 8% for gasoline, electricity and heating gas, plus the energy involved in food service, traffic control, maintenance, etc. raises the total to nearly 9000 BTU per passenger mile. Allowance of 20% for fuel overhead brings the total to about 10800 BTU per passenger mile. A 5% depreciation of the energy investments in aircraft and airports yields a total of 11300 BTU per passenger mile. Total energy consumption is increased by the overhead charges and depreciation from 1.08 Quadrillian BTU to 1.47 Quadrillian BTU. (Note, however, the possible double counting in the overhead accounts and the dual interpretation of the energy investment depreciation as mentioned above.)

In 1973-74, actions by the FAA, CAB and the airlines increased load factor to about 58% and raised the operational efficiency by about 5%. The result is an improvement in energy intensiveness from 15 passenger miles per gallon to 19 passenger mpg (8300 to 6550 BTU/passenger mile) for jet fuel. Assuming no change in the overhead rates, the total energy intensiveness appears to have dropped from 11300 to 9200 BTU/passenger mile.

If appropriate data were available, similar examples could be calculated for auto, bus and rail, wherein the total energy intensity, as computed for the air example, would include consideration of the direct fuel consumption, load factor, operational efficiencies, business and fuel overhead energy charges and energy investment depreciation.